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Semi-Annual Report
to the
National Aeronautic and Space Administration
for

Measurement of Reflectivities of Rocks, Minerals and Glasses in the Vacuum Ultra-Violet

NASA Grants NSG 7203 and 9056

Principal Investigator: Bruce Hapke

July 29, 1977

PROGRESS REPORT

1. Introduction

This report is a brief summary of the research carried out under NASA Grant NSG 7203 for the period 1 March 1976 - 28 Feb. 1977 and presently being continued under NASA Grant NSG 9056. The purpose of this laboratory research is to ascertain the kinds of compositional information which might be present in the vacuum UV reflection spectra of possible planetary surface materials and to provide a basis for the interpretation of present and future observations of the moon and planets.

Progress achieved to date may be briefly summarized as follows: (1) Assembly of reflectance apparatus; (2) Verification that compositional information exists in the vacuum UV; (3) Investigation of the effect of surface condition on the specular reflectance spectra; (4) Demonstration that the major diagnostic specular peaks are also present in the spectra of powders, and that in addition other diagnostic information may also be present.

2. Apparatus:

The apparatus was assembled and aligned. It consists of the following components, shown schematically in Fig. 1:

a) A 1 torr, 500 W, H discharge lamp, with power source.

b) A Jarrell-Ash 0.5m Seya-Namioka monochrometer, with platinized, holographic grating and differentially-pumped vacuum system.

c) A detector consisting of a rotatable, sodium salicylate coating, optically connected by a light pipe to a photomultiplier tube. The light pipe can be rotated to look alternately at the incident and reflected beams. Presently we are chopping the incident beam and measuring the photocurrent with a synchronous detector. We are now in the process of converting to a photon counting system to decrease noise and increase efficiency for very dark surfaces.

3. Experimental Results

a. Specular Reflectivities

The specular reflection coefficients of polished surfaces of several minerals have been measured over the ranges 5-15eV (2500-800Å). Typical spectra are shown in Figs. 2-5. Also shown on Fig. 2 is a spectrum of SiO_2 due to Sigel (1971, Phys. Chem. Solids, 32, 2373), illustrating the good agreement between our measurements and others'. Minor differences can be ascribed to the condition of the two surfaces. For most simple minerals the reflection coefficient rises to a sharp primary maximum in the 7-12 eV range, followed by several secondary maxima. The wavelengths of the maxima are different for each mineral and therefore can potentially be used as a remote-sensing compositional indicator. For instance, SiO_2 has a maximum at 10.5eV, augite at 10.25eV, adularia (K-feldspar) at 9.5eV, forsterite at 8.5eV, and fayalite at 7.5eV. The nature of the primary maximum is uncertain, but is thought to be associated with absorption by the formation of an exciton pair, with transition energy slightly less than the valence-conduction band gap (Nitsan and Shankland, 1976, Geophys. J. R. Astr. Soc., 45, 59).

Shortly after we began measuring the spectra it became apparent that they were dependent on surface condition. Therefore we temporarily set aside our program of systematic measurement of minerals to study the effect of surface preparation. The following variables were studied: (1) degree of polish, ranging from fractured and ground surfaces, to coarse and finely-polished surfaces; (2) polishing medium (H_2O and C Cl_4); (3) cleavage in dry, inert atmosphere vs laboratory conditioned air; and (4) effects of acid etch. It was found that the most important factor is surface roughness. The effect of a poor polish is to lower the spectra everywhere, and especially in the maxima, so that the contrast of the bands is decreased. The relative heights of the bands may also be changed. Nevertheless, the bands can usually still be recognized (Fig. 5). This result is important because the presence of cracks, bubbles and inclusions frequently prevents a natural mineral surface from taking a good polish.

Since planetary surfaces subjected to hyper-velocity impacts will contain materials which have been vitrified and vaporized, a study of the effects of melting and deposition from a vapor phase was also begun. Our preliminary result is that these processes may change the overall slopes of the spectra and the relative amplitudes of the maximum, but the main peaks are still recognizable in the spectra. Fig. 4 illustrates this result for augite: the peaks at 10.25eV in the ground surface is surpressed in the vitrified and augite-vapor-coated surfaces, but the maxima at 7.75 and 11.25eV are still prominent.

b. Reflectivities of Powders

Diffuse reflection spectra of several minerals ground to less than 37μ are shown in Figs. 2-5. Since most planetary surfaces are pulverized, it was an extremely important result to find that the main specular maxima are still recognizable in the diffuse spectra of the powders. Often the contrast on the high-energy side of the primary band is almost as strong in the powder as in the polished surface.

A second finding is that the diffuse reflectivities of powders generally increases with wavelength for energies below about 8eV (1500 Å). This occurs because the powders are no longer completely opaque, so that some volume-scattered light contributes to the reflectivity. Using this effect we hope to be able to study absorption bands in minerals in the little-studied 1500-3000Å range. One presently-puzzling band is a minimum at 6.5eV in several substances.

c. Fluorescence

We recognize that UV-stimulated fluorescence could be contributing in a major way to the diffuse reflectivities of some of the rough or powdered surfaces. In the coming year we will investigate this possibility by placing between the surface and detector a filter of some suitable material, such as S-1 SiO_2, which has an edge around 2000Å. Any residual reflectivity would be due to fluorescence and will be subtracted from the spectrum to yield true reflectivity.

4. Theoretical

Although we have not yet done so, we intend to carry out Kramers-Kronig analyses of the specular reflection coefficients R to yield the real and imaginary parts n and k of the indices of refraction. In preparation for such an analysis, a model of a Lorentz oscillator was used to generate an artificial reflectivity spectrum, which was then subjected to a K-K analysis to see how well the complex refractive index could be recovered. The spectrum was then degraded (by increasing the damping constant) to simulate the effects of imperfect polishing. Figure 7 shows the results. It was found that, although (as expected) the amplitudes of n and k deduced from the degraded spectrum were reduced, the area under the k curve was not appreciably affected, so that it should be possible to deduce oscillator strengths even from surfaces with poor polishes.

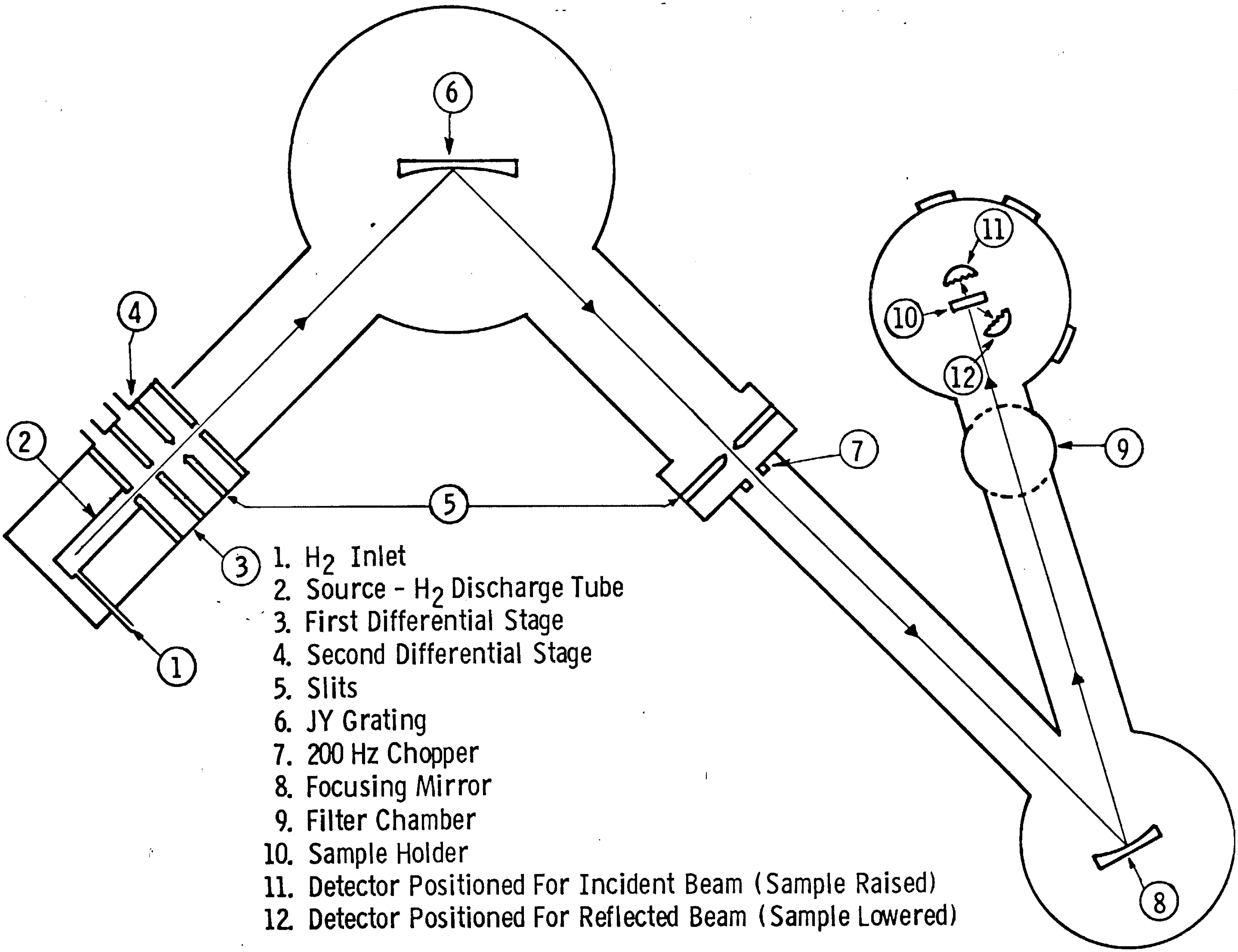
5. Personnel

The following persons have contributed to the research described here:

B. W. Hapke, P.I.
A. J. Cohen, Co-I
W. D. Partlow, Co-I
J. Wagner, Graduate Student Researcher

6. Papers and Meetings

Because of the preliminary nature of the results described here, no papers have yet been published. We intend to prepare a paper for the next Lunar Science Conference or similar appropriate meeting. A related paper which incorporates some of our preliminary spectra "Interpretation of Optical Observations of Mercury and the Moon" by B. Hapke was presented at the Conference on Comparisons of Mercury and the Moon, Houston, Nov. 1976 and has been accepted for publication in Physics of Earth and Planetary Interiors.



1. H_2 Inlet
2. Source - H_2 Discharge Tube
3. First Differential Stage
4. Second Differential Stage
5. Slits
6. JY Grating
7. 200 Hz Chopper
8. Focusing Mirror
9. Filter Chamber
10. Sample Holder
11. Detector Positioned For Incident Beam (Sample Raised)
12. Detector Positioned For Reflected Beam (Sample Lowered)

Fig. 1A — Differentially pumped vacuum ultraviolet monochromator-reflectometer

W. Partlow
b.r. - r.m. 8-2-77

Dwg. 6416A08

Dwg. 6416A06

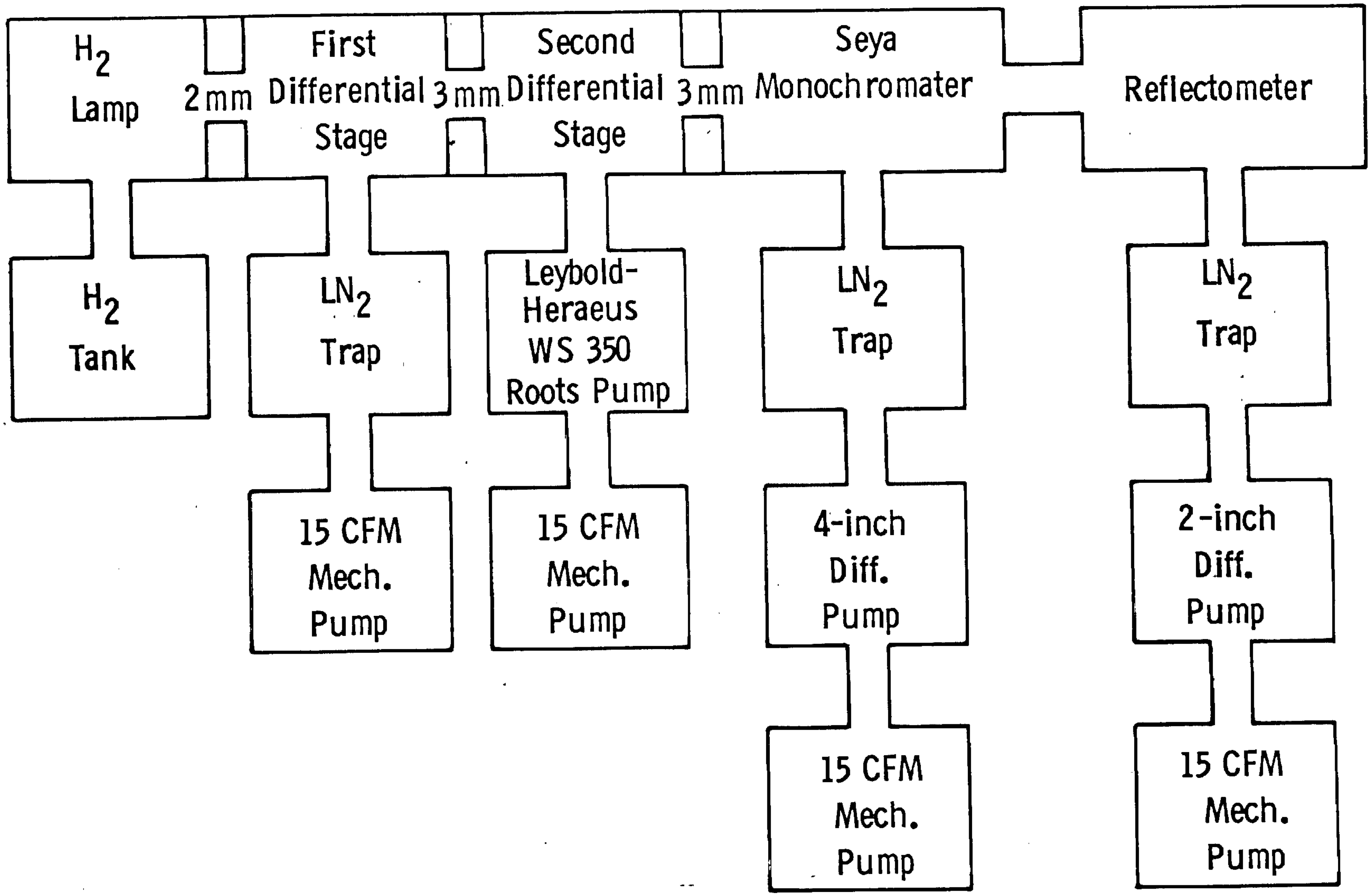


Fig. 1B — Schematic of pumping equipment

W.D. Partlow
l.t. - k.b. 8/1/77

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W.D. Partlow
l.t. - k.b. 8/1/77

Curve 691341-B

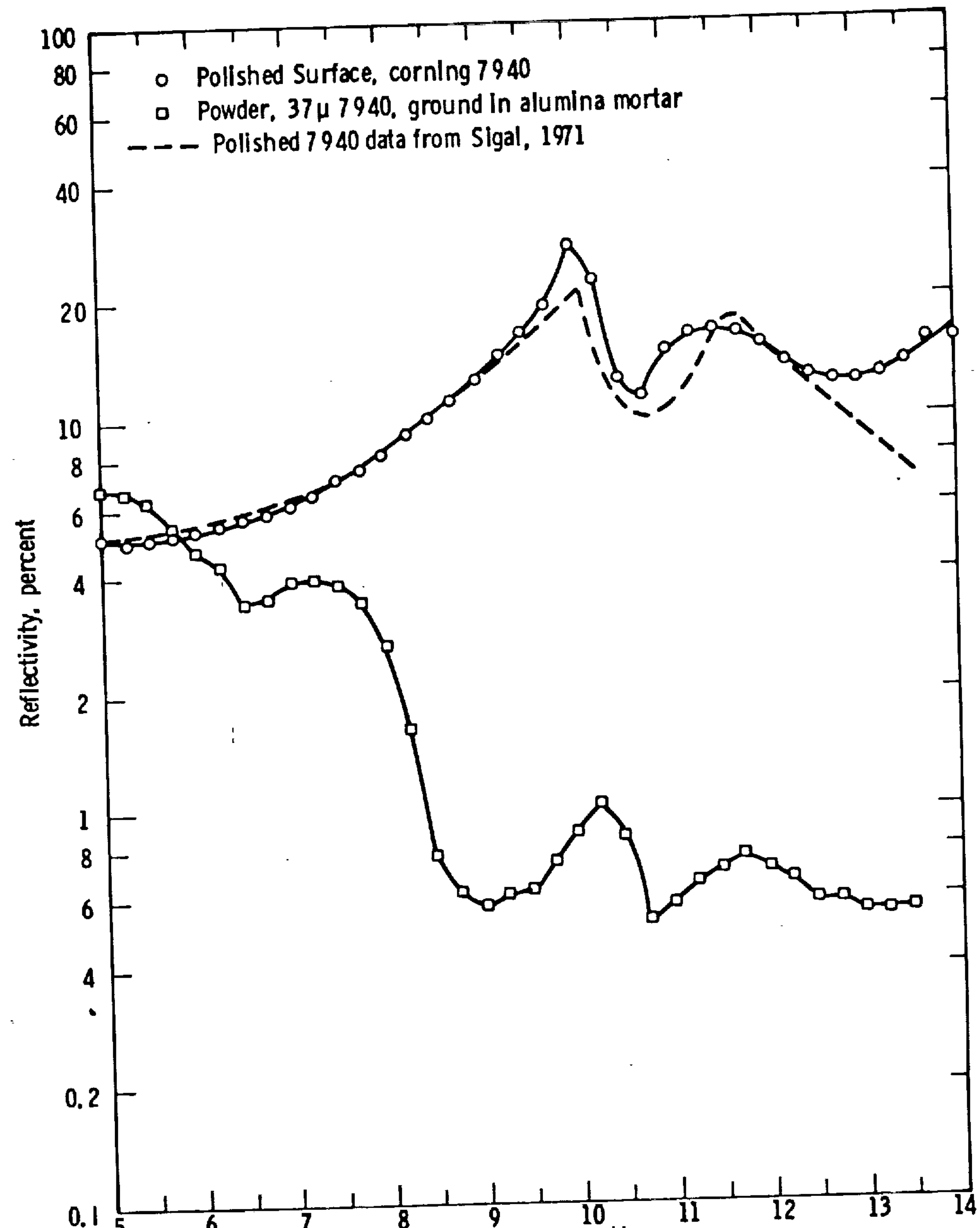

Fig. 2 – Normal incidence reflectivity of corning 7940 fused silica polished surface and lightly packed powder. Polished surface data is compared to data in the literature (Sigel, 1971)

Curve 691341-B

W.D. Partlow
l.t. - k.b. 8/1/77

Curve 691344-B

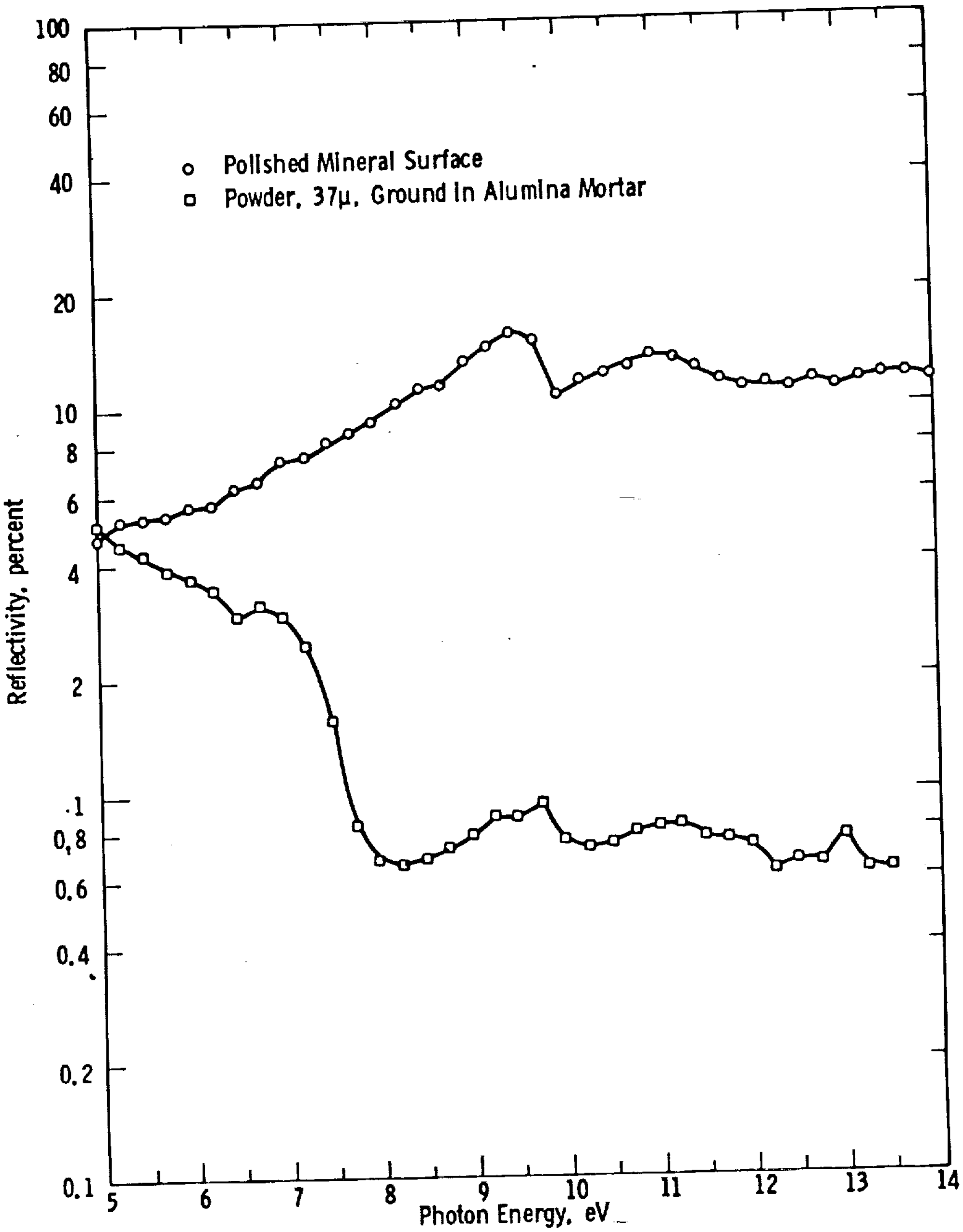

Fig. 3 – Adularia (Pizzo Lucindro, Ticino Switzerland), polished surface and lightly packed powder

Curve 691344-B

W.D. Partlow
l.t. - k.b. 8/1/77

Curve 691342-B

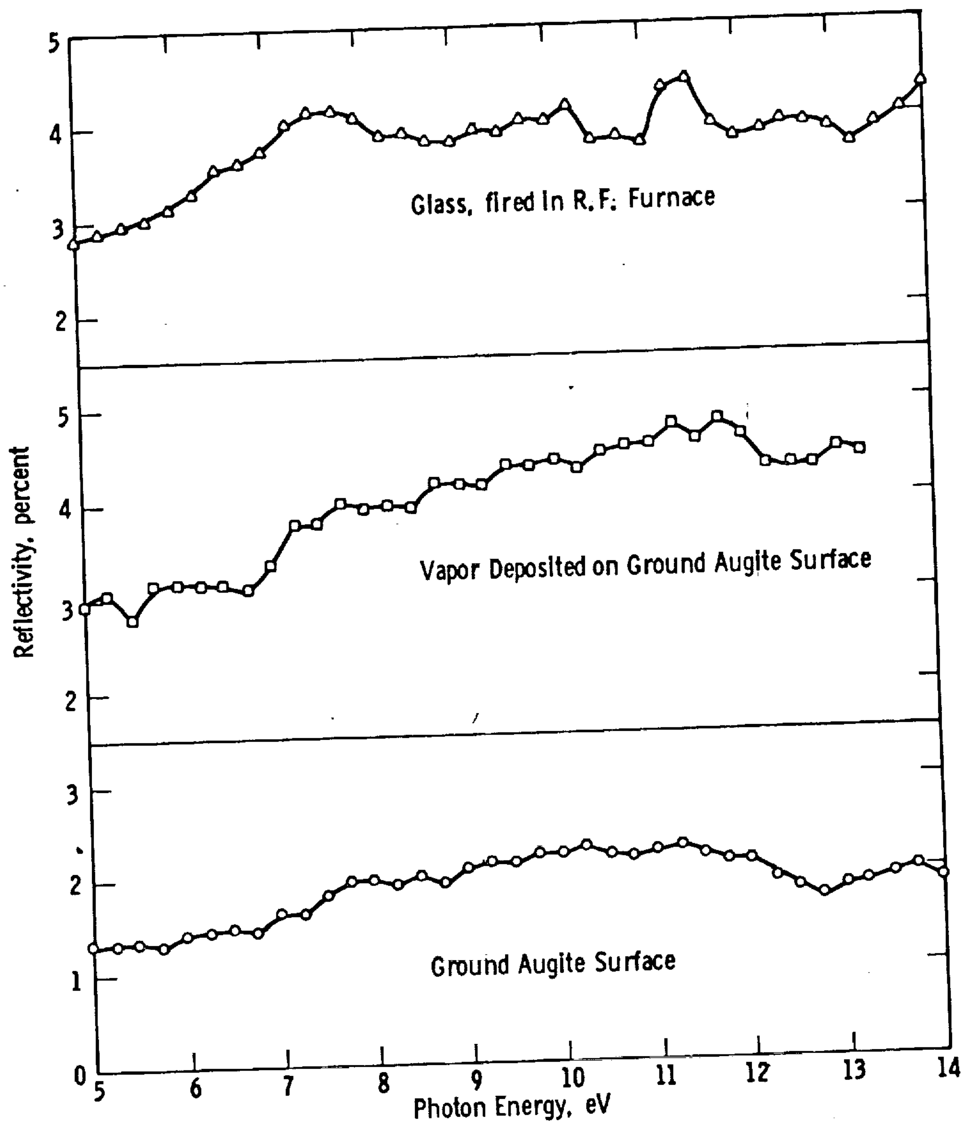

Fig. 4 – Lerozier (France) augite surfaces prepared several ways

Curve 691342-B

W.D. Partlow
l.t. - k.b. 8/1/77

Curve 691343-B

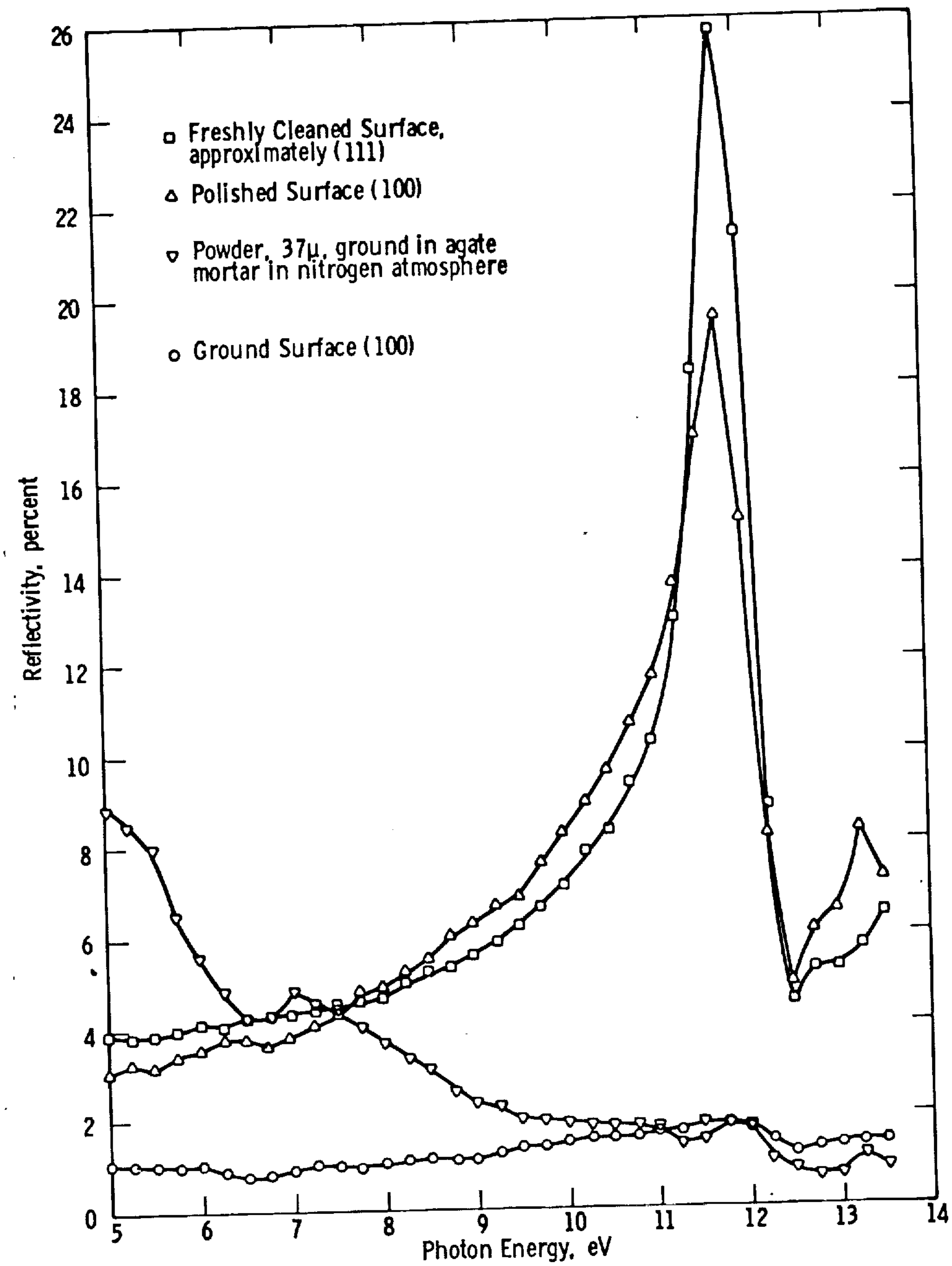

Fig. 5 – Synthetic magnesium fluoride, Harshaw Corp.

Curve 691343-B

W.D. Partlow
l.t. - k.b. 8/1/77

Curve 691347-B

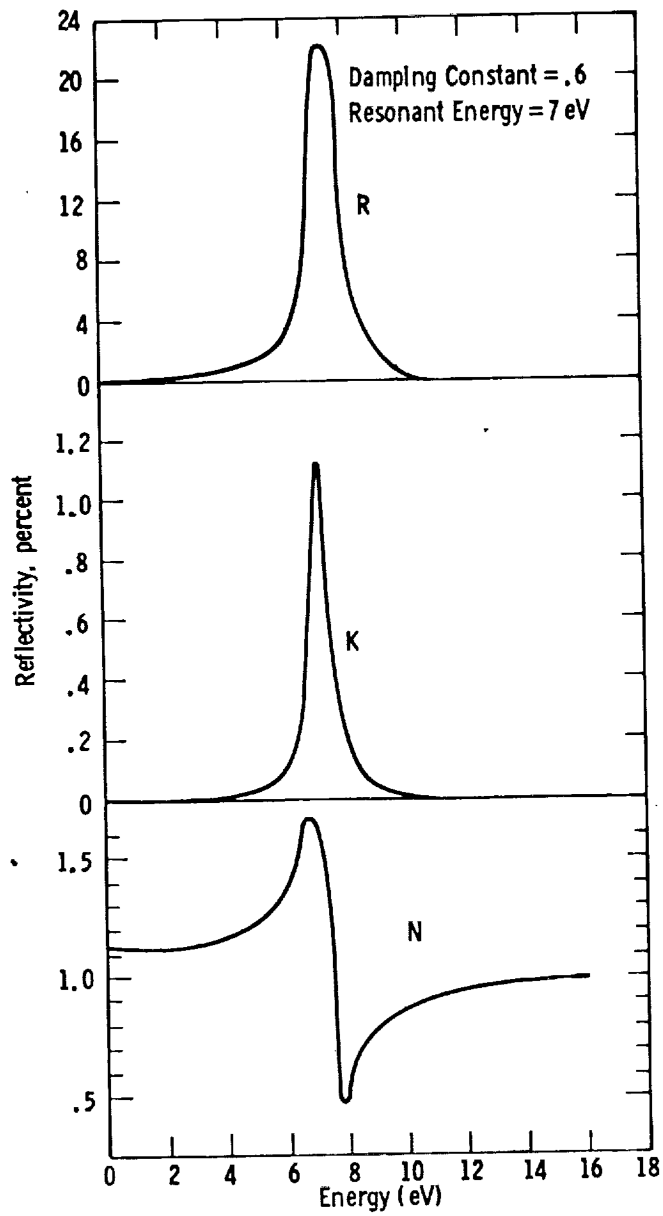

Fig. 6 – Theoretical R, N, and K for a lightly damped harmonic oscillator

Curve 691347-B

W.D. Partlow
l.t. - k.b. 8/1/77

Curve 691348-B

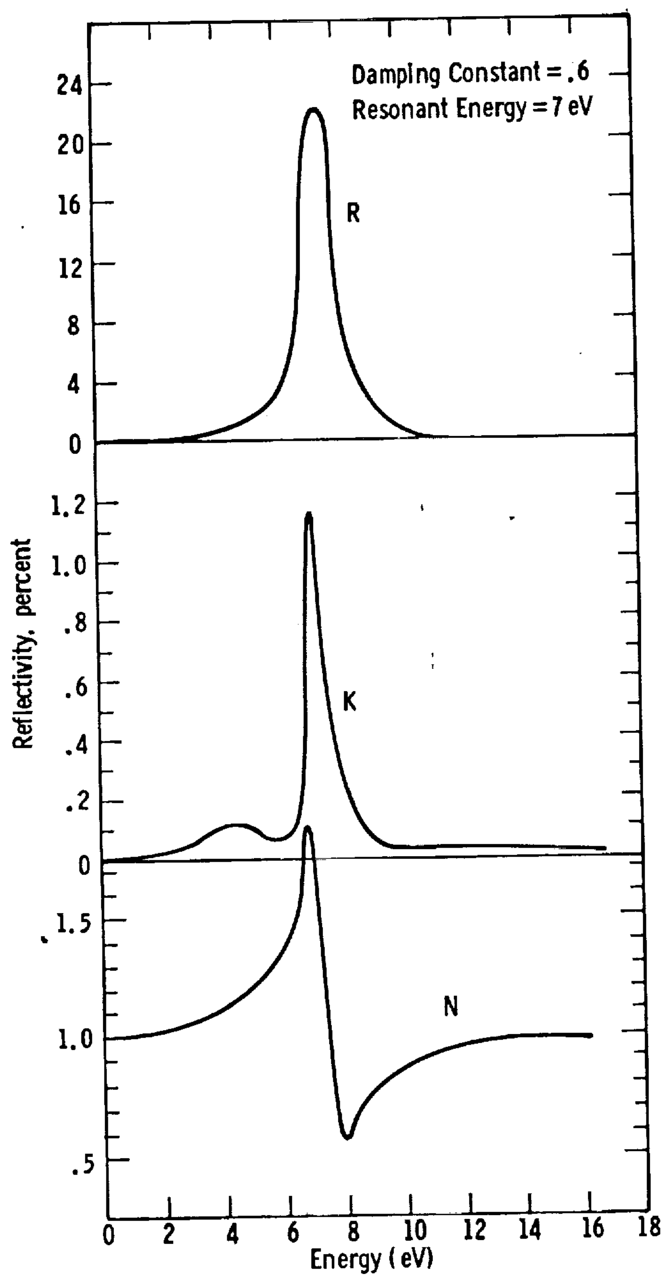

Fig. 7 – N and K determined by Kramers–Kronig inversion of R for a lightly damped harmonic oscillator

Curve 691348-B

W.D. Partlow
l.t.-k.b. 8/1/77

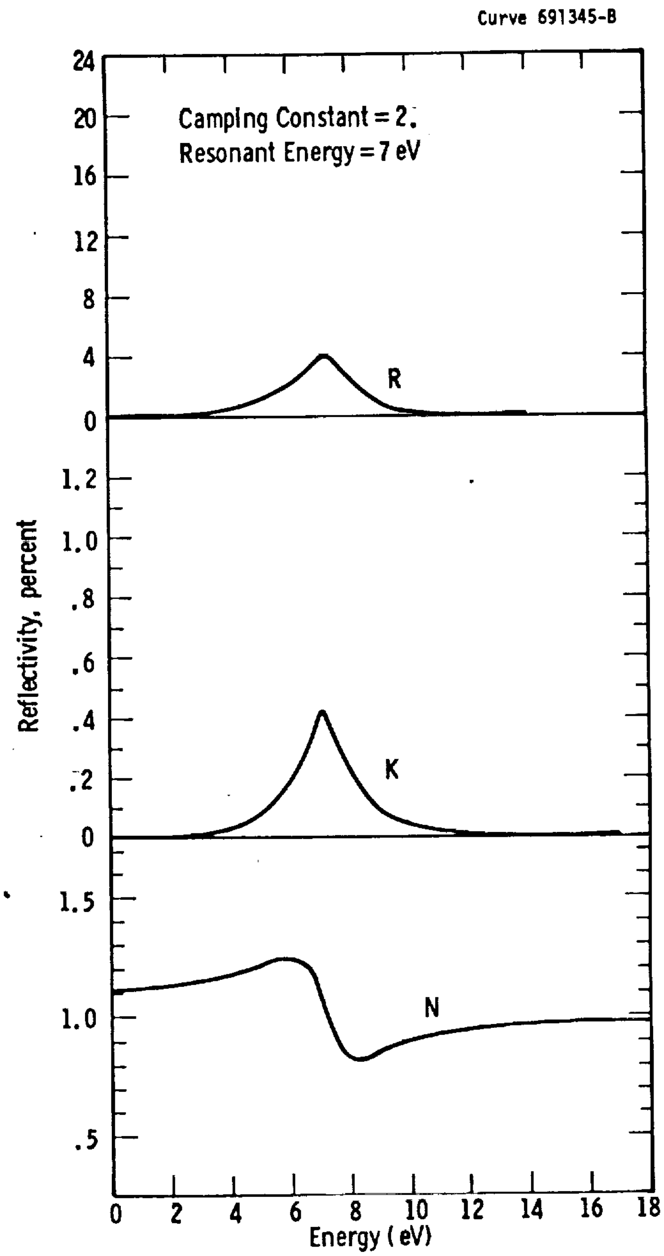

Fig. 8 — Theoretical R, N, and K for a strongly damped harmonic oscillator

Curve 691345-B

W.D. Partlow
I.t. - k.b. 8/1/77

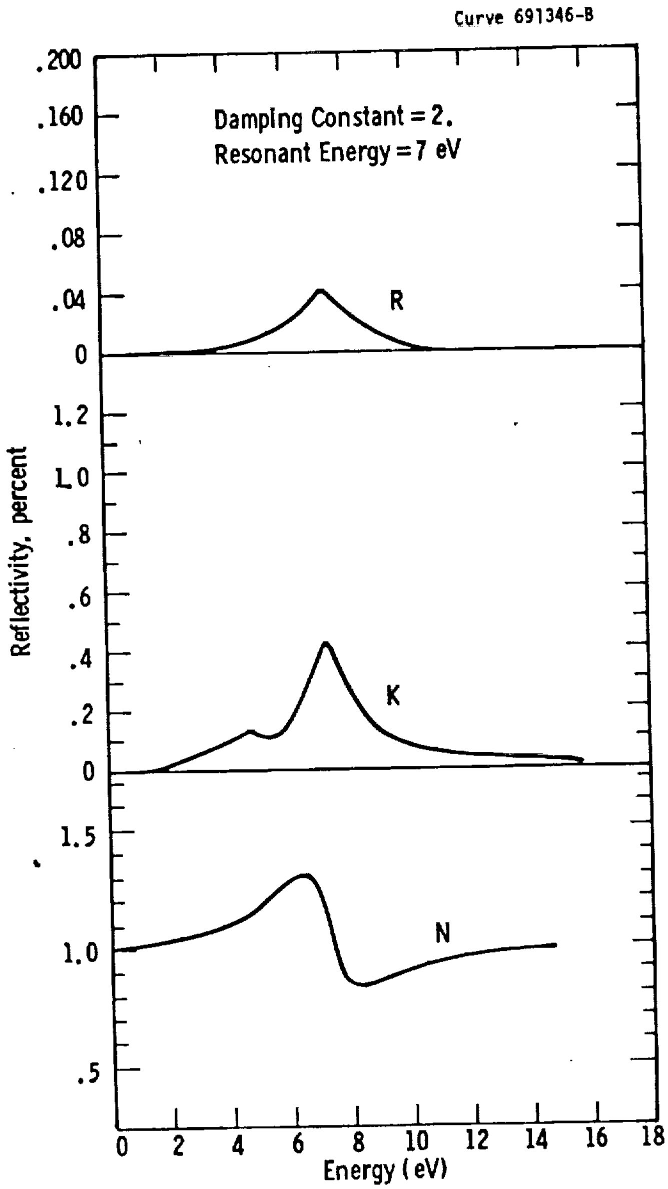

Fig. 9 – N and K determined Kramers–Kronig inversion of R for a strongly clamped harmonic oscillator

Curve 691346-B